The Effects of Spatial Disorientation on Working Memory and Mathematical Processing

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14. ABSTRACT

Previous research shows that participants exhibit impairments in spatial memory while experiencing various types of spatial disorientation (SD) in a laboratory environment. With regard to aviation-based SD, a pilot's ability to think his/her way out of a dangerous situation may be impaired when disoriented. The present study assessed the effects of SD on cognitive functioning during simulated flight. Thirty-six UH-60 aviators participated in the study. Participants were asked to perform cognitive tests (presented aurally) as they performed oriented and disoriented flight conditions. Cognitive tests consisted of a digit span task as well as an addition task. Participants' accuracy was significantly worse for the disoriented condition than the two oriented conditions for both cognitive tests. The current study provides support that SD can negatively impact cognitive performance. These results can be used to aid future cockpit display design and training techniques aimed at mitigating SD.

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Introduction

Spatial disorientation (SD) is defined as a pilot's failure to correctly sense the position, motion or attitude of his/her aircraft or him/herself with respect to the surface of the earth (Benson, 1999). Previous reports have shown that SD plays a significant role in both the number and outcome of military rotary wing aircraft accidents. Braithwaite, Groh, and Alvarez (1997) reviewed summaries of over 900 U.S. Army rotary wing accidents from 1987 to 1995 and found 30% of all accidents involved SD. In addition, the average cost of SD related accidents was significantly greater than the average cost of non-SD accidents, both in terms of monetary costs and lives lost. Spatial disorientation is also a causal factor in U. S. Air Force (USAF) rotary wing accidents as Matthews, Previc, and Bunting (2003) found a 27% incidence of SD in USAF helicopter accidents.

Pilots rely on their visual, vestibular, and proprioceptive systems for orientation information while in flight. Approximately 80% of the information used for orientation is dependent on the visual sense (DeHart & Davis, 2002). The visual system is not without its flaws, however, as there are several size and distance illusions common to flight. The vestibular system is located in the inner portion of each ear and contains the semicircular canals and otolith organs, which provide information about head position and motion. The two otolith organs respond to changes in linear acceleration and gravity, while the semicircular canals are responsive to angular acceleration. In other words, these organs respond not to constant velocity, but to changes in the rate of motion (i.e., starts and stops), a major inadequacy of the vestibular system (DeHart & Davis). While the visual and vestibular systems are of utmost importance to maintaining spatial orientation, the proprioceptive system plays a supporting role. The proprioceptive system is the body's sense of limb position. Within muscles and tendons, receptors respond to changes in muscle length and tension while receptors in the skin can detect points of contact between the body and the environment (DeHart & Davis). If the information received from these systems conflict, illusions can occur and SD results.

Researchers categorize aviation-based SD into three types: Type I (unrecognized), Type II (recognized), and Type III (incapacitating; Dehart & Davis, 2002; Previc & Erocline, 2004). When pilots experience Type I disorientation, they are not aware that they are disoriented and feel that the aircraft is responding well to inputs. Many accidents result from Type I disorientation. Type II SD is characterized by the pilot's conscious awareness of some conflicting orientation cues. The pilot is aware that something is wrong but can still control the aircraft or elect to transfer the controls to another pilot. Only a minority of SD mishaps are credited to Type II SD. Finally, Type III SD is the most debilitating but least understood. With Type III disorientation, pilots are aware that they are disoriented; however, they are often so confused that incorrect flight adjustments are made and little can be done to recover. Pilots may be so incapacitated and afraid that they freeze on the controls. Type III disorientation is very rare (Previc & Ercoline). Figure 1 illustrates the progression of Type I to Type III SD.
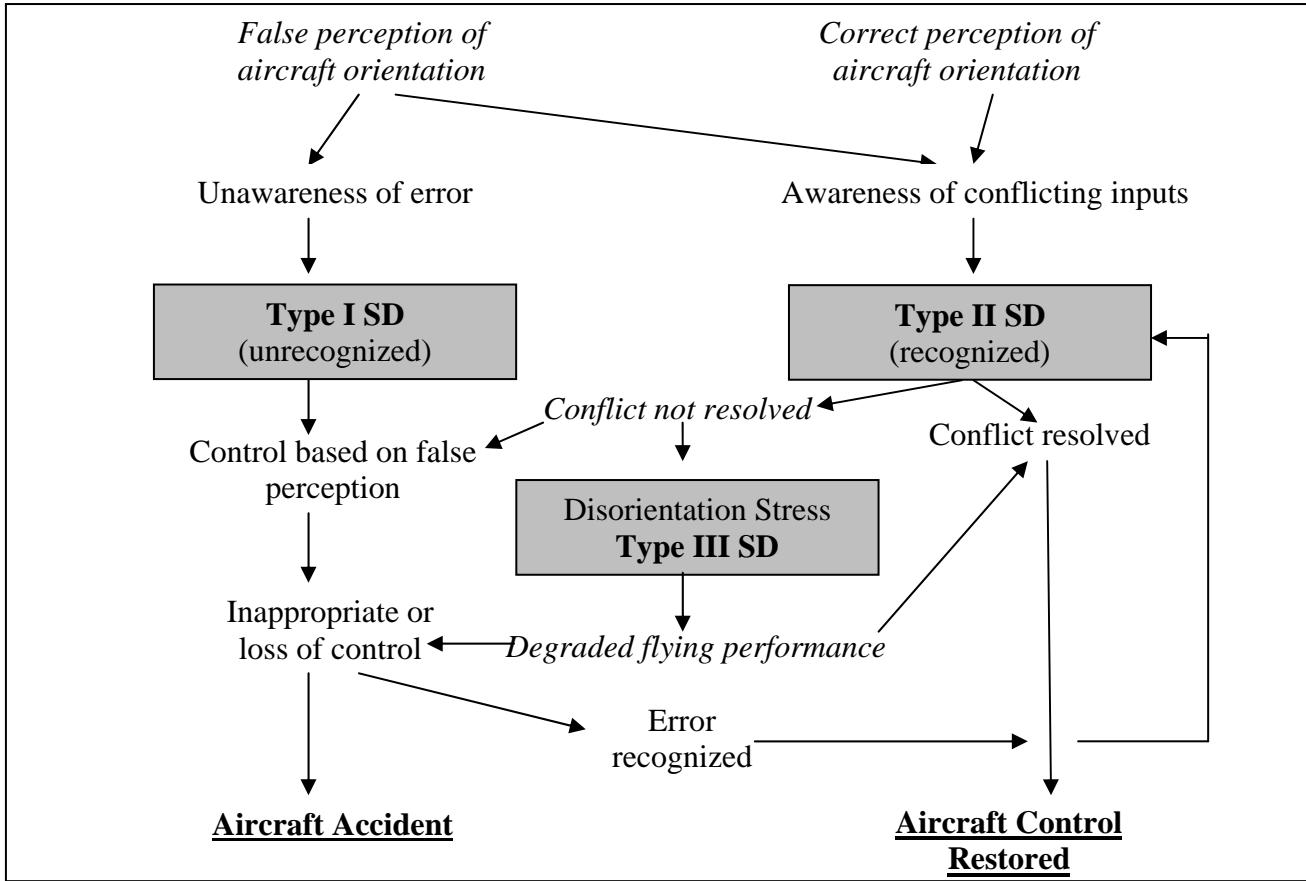
Figure 1. The progression of spatial disorientation (Previc & Ercoline, 2004).

There are several factors that can increase a pilot's susceptibility to SD, including environmental, psychological, and physiological factors. Environmental factors include degraded visual environments (DVE) and night flying, which reduce the amount and quality of ambient visual cues. Formation flying in adverse weather conditions "is probably the most likely of all situations to produce disorientation" (DeHart & Davis, 2002). Previc and Ercoline (2004) cite three reasons as to why formation flight in DVE is particularly conducive to SD: (1) pilots must rely on the lead aircraft for orientation information, (2) the un-availability of visual cues means that pilots rely on vestibular cues, which are often unreliable in flight, and (3) the extended period of time in which instrument cross check is broken. Cross checking aids the pilot in recognizing an instrument failure. For example, if a pilot's altimeter indicates the aircraft is descending, the vertical speed should also provide the same indications. Common psychological and physiological factors include overconfidence, fatigue, and health-related conditions and medications (Gawron, 2004).

One example of SD that is inherent to rotary wing flight is vection, which is the "visually induced perception of self-motion" (DeHart & Davis, 2002). Vection is commonly experienced, for example, when one is stopped at a traffic light and a side-adjacent car backs up a few feet suddenly. The driver of the stopped car might slam on the brakes thinking he/she is lurching forward when in fact the car is still. Vection is one of the factors that make close formation

flying so hazardous; the forward, aft, up or down movement of a lead or adjacent aircraft may be misinterpreted as movement of a pilot's own aircraft in the opposite direction. Vection is also likely to occur in rotary wing flight while hovering over water (Previc & Ercoline, 2004).

<center>Spatial disorientation and cognition</center>

The "posture first principle" explains that when balance and orientation are unstable, there is a natural tendency to direct all mental resources to regaining orientation and stability. This prioritization may draw on resources and as a result, degrade secondary tasks (Gresty, Golding, Le, & Nightingale, 2008).

Previous research has explored the relationship between orientation and cognitive processes. Kerr, Condon, and McDonald (1985) found that maintaining an unstable posture produced more errors in recall memory tasks that required spatial processing than a non-spatial memory task. Specifically, the Brooks spatial and verbal memory task was used which requires participants to remember the placement of a set of numbers in a 4 by 4 matrix. The interference of spatial tasks with balance regulation has been documented in patients with vestibular abnormalities and healthy individuals (Yardley, Gardner, Bronstein, Davies, Buckwell, & Luxon, 2001) Patients with vertigo have been found to perform poorly on tests of mental arithmetic (Risey & Briner, 2001). In addition, stimulation of the vestibular system has been shown to produce changes in the hippocampus, an area of the brain that plays a major role in memory (Smith, Zheng, Horii, & Darlington, 2005).

Some aviation-based studies examining the effects of SD on cognition have measured cognitive processing *after* experiencing SD. In these studies, participants are exposed to disorienting motion, then exit the device, and complete various cognitive tests. Studies examining postponed effects of SD on cognitive functioning have found decreases in scores on letter cancellation tests and digit symbol substitution tests, two measures of attention and visual scanning (Sen, Yilmaz, & Tore, 2002) and figure rotation, especially when sleep deprived (LeDuc et al., 2000). However, the time between stimulus and testing may dilute any subtle effects of SD on cognitive performance.

Of the few studies that have examined cognitive performance *during* SD, they have been limited to very basic SD illusions using a general population. Nevertheless, they have demonstrated that cognitive processing is negatively affected during SD. Gresty, Waters, Bray, Bunday, and Golding (2003) found an increase in the variability in performance on spatial tasks more so than verbal tasks using the Brooks spatial and verbal matrices. The disorienting stimulus was a conflict between passive self motion and visual flow. More recently, Gresty et al., (2008) examined cognitive performance during three disorienting stimuli: head rotation, vection, and Coriolis stimulation. In all three scenarios, participants were asked to complete a test of spatial ability and reaction time presented visually on a lap-top computer. Declines in spatial ability were also found. It should be noted that these declines were found in both vestibular (i.e., head rotation and Coriolis stimulation) and visual (vection) SD.

<center>3</center>

Spatial disorientation and workload

Recognized SD increases a pilot's workload during a flight. At a simplified level, workload can be defined as the cost of accomplishing a task for a human operator. These costs can be fatigue, stress, and errors among others (Hart, 2006). According to the information processing model, an operator has only a limited amount of resources to complete a task, including both physical and mental. A high workload task would demand more resources than are available, and performance on the task would decline (Hendy, East, & Farrell, 2001). Consequently, there exists the potential for workload to confound the effects of recognized SD on cognition. It should be noted that SD does not always increase workload. In unrecognized SD, such as controlled flight into terrain (CFIT), the pilot is oblivious to the disorientation.

Research objectives

More information is needed on the cognitive functioning of aviators while experiencing spatially-disorienting motion. There are different types of SD, and not all are equally-likely to result in an accident. Under some conditions, it is possible for deficits in cognition to turn minor mistakes into a fatal crash. By identifying the source of those mistakes, potential measures can be identified that impede or halt the escalation of minor errors to fatal consequences. While research shows impairments in spatial memory during various types of SD (Gresty, et al., 2003; Gresty, et al., 2008), these studies are limited to basic SD in a laboratory setting (e.g., head movements and projection screens) using a general population. To expand this line of research to an aviation setting, the present study examined how SD impacts other aspects of cognition, such as working memory and mathematical processing, in an applied environment (i.e., an NUH-60 research flight simulator) using a representative sample of Army aviators. The overall research objective was to examine the effect of recognized SD on cognitive processing. The effects of SD were compared to oriented flight and oriented flight with increased workload. That is, there were three experimental conditions: *disoriented in formation*, *oriented in formation*, and *oriented*. It was hypothesized that aviators would perform worse while experiencing the disoriented condition compared to two oriented conditions in terms of performance on the cognitive tests. In addition, performance during the *oriented in formation condition* was hypothesized to be poorer than the *oriented* condition, due to the increased workload.

Methods

Participants

Eligible participants included both male and female UH-60 rated pilots between the ages of 19 and 65 years. Research demonstrates that age-related decrements in working memory (specifically digit span performance) are not statistically significant until the age of 75 (Norman, Kemper, & Kynette, 1992). However, after the age of 65, there is increased risk of vestibular dysfunction and hearing loss (National Institutes of Health, 2002; National Institute on Deafness and Other Communication Disorders, 2002). Therefore, the study population was limited to the maximum age of 65 to prevent the influence of age, vestibular health, or hearing ability on the results.

Interested participants were required to be active duty Army helicopter pilots, Department of the Army civilian, or contract helicopter pilots around Fort Rucker, Alabama. All pilots were deemed healthy by a current "fit for duty" flight physical, and had flown a UH-60 helicopter or simulator within 6 months of participating in the study. Participants were required to be free of any hearing loss or vestibular abnormities. The participants received an otoscopic examination, a middle ear examination (tympanogram), and an air-conduction audiogram. Participants were required to have hearing "within normal limits" as defined by American National Standards Institute. A power analysis indicated a total of 36 participants were needed for the study.

Equipment

The U.S. Army Aeromedical Research Laboratory's (USAARL) NUH-60 research flight simulator (figure 2) consists of a six-degree-of-freedom motion simulator compartment containing a cockpit, instructor/operator station, and observer station. It is equipped with a digital image generator system that simulates natural helicopter environment surroundings for day, dusk, or night, and with blowing sand or snow. It has been used to generate SD in numerous protocols conducted at the USAARL (Braithwaite et al., 1998; LeDuc, Johnson, Ruyak, & Estrada, 1999; LeDuc et al., 2000). The NUH-60 research flight simulator is also equipped with a research data acquisition system (RDAS), consisting of a DELL Latitude laptop computer that can sample and store up to 128 variables of flight parameters at a rate of 30 frames per second. It should be noted that the audio system in the simulator was set to level 1, corresponding to a sound level of 82.0 decibels (A-weighted; dB[A]) at the right-seat pilot position. For all flights, the participant was seated in the right pilot seat while the research aviator was seated in the left pilot seat.

Figure 2. The USAARL NUH-60 research flight simulator.

Flight profile

The entire flight profile was completed in approximately 75 minutes. It contained two *oriented* conditions, two *oriented in formation* conditions, and two *disoriented in formation* conditions (table 1). The *oriented* conditions involved straight and level flight in visual meteorological conditions. Participants were instructed to climb to an altitude of 7500 feet mean sea level (MSL), and at that time, the presentation of the cognitive test began. The *oriented in formation* conditions involved pilots flying in DVE while performing airborne communications. Participants were instructed to follow a pre-recorded lead aircraft as it climbed to an altitude of 8000 feet MSL, and at that time, the presentation of the cognitive test began. The *disoriented in formation* conditions involved the participant flying in formation with a lead aircraft in DVE while performing airborne communications and without the use of flight instruments. Figure 3 depicts the view of the covered instrument panel. Once the aircraft reached 18,000 ft MSL, the lead aircraft disappeared, leaving the pilot disoriented, and the cognitive testing began. To motivate the participants, they were instructed that successful performance on the cognitive tests would result in their instrument panel being restored. It should be noted that if a participant lost visual contact with the lead aircraft before it disappeared from the scenario, the testing began, as the participant was considered disoriented.

Profile scripts are included in appendix A. Flight performance data were recorded for each condition, and motion simulation was used for the two oriented conditions. Due to the need to use the crash over-ride feature in the disoriented conditions, motion simulation was not used in these conditions.

Table 1.
Flight profile.

Oriented	Oriented in formation	Disoriented in formation
Single aircraft straight and level flight	Following leadship (limited maneuvering)	Following leadship (vigorous maneuvering)
Good visual conditions (11 miles visibility, no clouds)	Degraded visual conditions (0.5 miles visibility)	Degraded visual conditions (0.5 miles visibility)
No airborne communication requirements	Airborne communication requirements	Airborne communication requirements
All aircraft flight and system instruments fully functional and available to the pilot	All aircraft flight and system instruments fully functional and available to the pilot	Aircraft flight instruments unavailable to the pilot
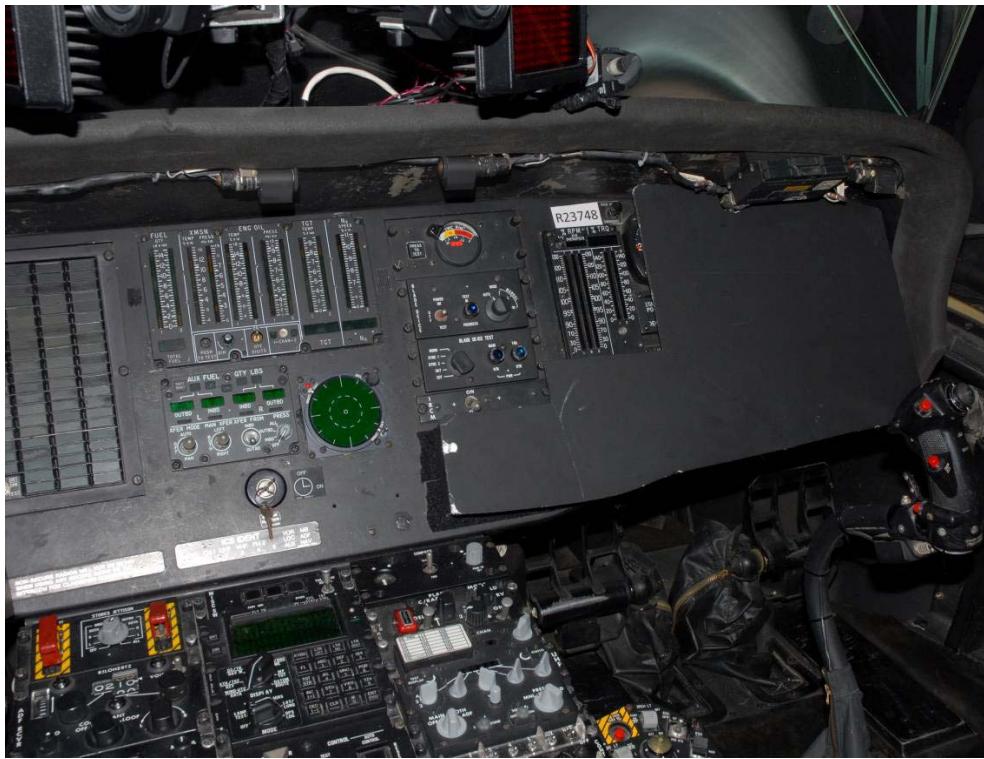
Figure 3. Example of covered instrument panel.

Assessments

The cognitive assessments included a digit span task as well as an addition task, two common and validated tests of working memory. These aspects of working memory are very important to successful aviation but have not yet been studied in relation to SD. As visual cues are essential to flight performance, these tests were presented aurally so as not to add to the pilot's visual workload. Presentation materials for the cognitive tests were digitally recorded to ensure consistency across all subjects. Each participant adjusted the loudness of the recordings according to his/her comfort.

A forward digit span task adapted from the Wechsler Adult Intelligence Scale (Wechsler, 1997) was used to assess working memory. A string of numbers was presented aurally at a rate of one per second and the participant was asked to repeat the digits in order. The number of digits increased by one until the participant either failed two consecutive trials of the same digit span length or completed the test. The maximum digit span length was nine digits. Participants' responses were recorded and analyzed using sound recording software to capture accuracy and response time data.

An addition task adapted from the Paced Auditory Serial Addition Task (PASAT) was used to assess mathematical functioning. The task involved presenting a series of single digit numbers where the two most recent digits must be summed (Tombaugh, 2006). For example, if the digits *4*, *9*, and then *2* were presented, the participant would respond with the correct sums, which are *13* then *11*. The traditional PASAT contains 61 items. For the present study, the digits were

presented at a rate of one every 3 seconds and only 19 trials were presented due to the time constraints of the disoriented condition. Participants' responses were recorded and analyzed using sound recording software to capture accuracy and response time data.

Due to the potential of simulator sickness to confound the results of the study, the Simulator Sickness Questionnaire (SSQ) was used to collect data regarding any simulator sickness symptoms the participants may have experienced. Simulator sickness is a form of motion sickness caused by physical motion, visual motion, or some combination of the two in a simulator. Developed by Kennedy, Lane, Berbaum, and Lilienthal (1993), the SSQ is a self-report checklist consisting of 16 symptoms that are rated by the participant in terms of severity. These symptoms include, but are not limited to headache, nausea, burping, sweating, fatigue, and vertigo. Participants rate each symptom on a Likert-type scale with the options "none," "slight," "moderate," and "severe." The SSQ yields a nausea, oculomotor, disorientation and total severity score. Participants were asked to complete the SSQ upon exiting the simulator (appendix B). The inclusion of the SSQ allowed the researchers to assess the effect of simulator sickness on performance. That is, if performance during the SD condition is poor and there are no symptoms of simulator sickness, then the researchers will be able to rule out the influence of simulator sickness on performance.

Design

The independent variable of interest was flight condition, and its three levels were *oriented, oriented in formation*, and *disoriented in formation*. Given the potential for workload to confound the effects of recognized SD in the present study, the *orientation in formation* condition (with no disorientation but increased workload) was included to examine the relationship between workload and SD. The dependent variables were the participants' accuracy and response times for the cognitive tests (addition and digit span). The present study employed a repeated measures design, whereby all participants experienced all testing conditions. The presentation of the conditions was randomized to eliminate possible order effects.

Procedures

The study protocol was approved by the U.S. Army Medical Research and Materiel Command Institutional Review Board. On Day 1 of the experiment, written informed consent was obtained from interested participants and then they completed the auditory and vestibular screenings. On Day 2, participants completed three practice trials of both the digit span and addition task in an office setting, and then completed the test flight. A research aviator, acting as a co-pilot, managed the research aspects of the flight and ensured the correct timing and sequencing of each maneuver. A research technician was inside the simulator for data collection purposes. The flight profile contained two *oriented* conditions, two *oriented in formation* conditions, and two *disoriented in formation* conditions in random order and the presentation of the cognitive tests was randomized to prevent any order effects. Immediately following the simulator flight, participants completed the SSQ. Before being released from the study, participants met with the study physician to ensure there were no lingering effects of the simulator environment.

<u>Results</u>

All statistical analyses were conducted using SPSS® 12.0 with significance set at an alpha level of .05. A repeated measures ANOVA was used to assess cognitive performance across the three flight conditions (*oriented*, *oriented in formation*, and *disoriented in formation*) for each dependent measure.

Demographic data

Thirty six UH-60 aviators participated in the study with an average age of 29.9 years ($SD =$ 5.2) and average flight experience of 715.6 total flight hours ($SD = 1122.4$). Four participants were female. Figure 4 illustrates the distribution of the participants' current job positions.
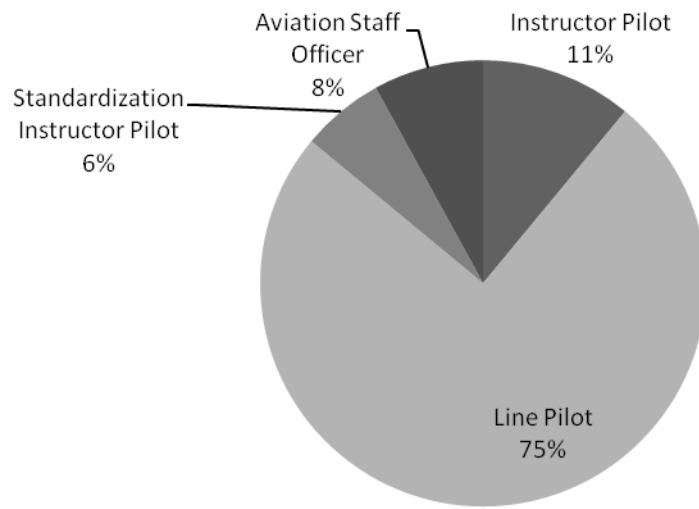
Figure 4. Distribution of job positions.

Flight performance

Flight performance data were collected using the RDAS to provide researchers the opportunity to verify that the participants were disoriented during the disoriented conditions. For the present study, control reversal errors (CRE) specific to aircraft roll were examined as a sign of disorientation. A similar technique was used in Estrada, LeDuc, Gallagher, Greig, and Dumond (2006). Control reversal errors occur when a pilot moves the control in such a way so as to increase the undesirable situation (Liggett & Gallimore, 2002). Figure 5 presents a single pilot's flight performance (representative of many participants' performances) during the *disoriented in formation* condition and shows that the pilot was not making inputs in a coordinated manner to correct the rolling of the aircraft.
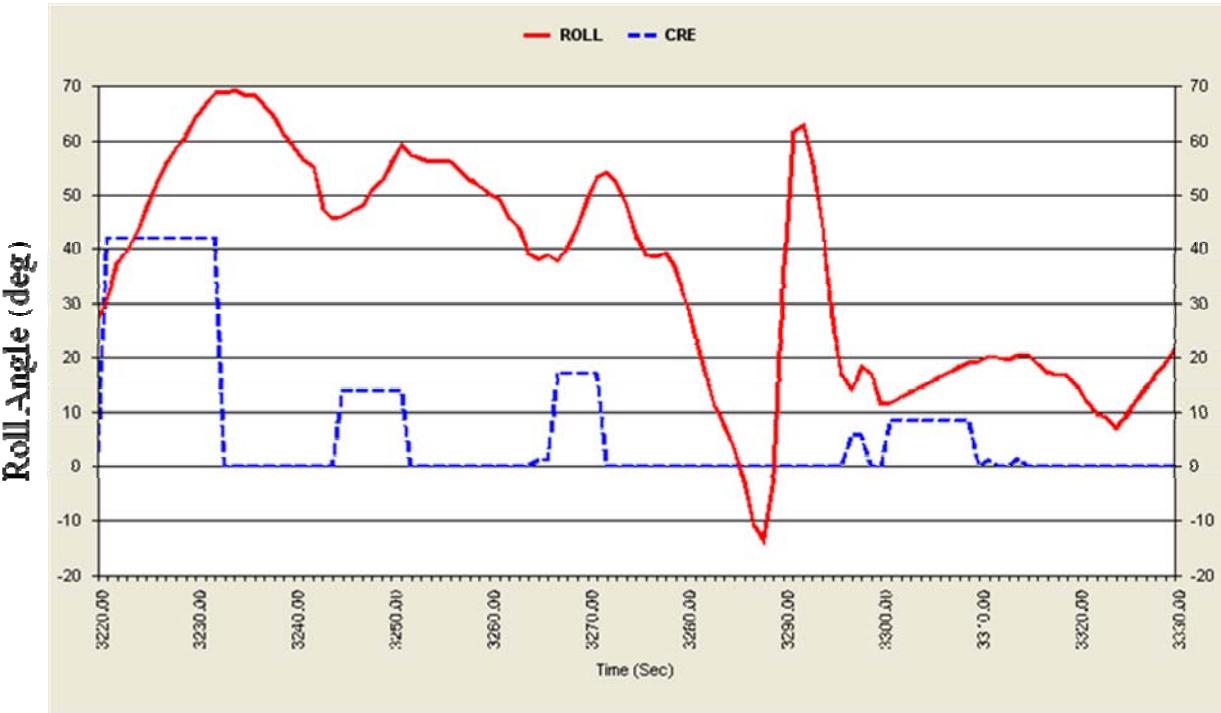
Figure 5. Flight performance during *disoriented in formation* condition. Note: the solid line indicates the aircraft roll and the dashed line indicates control reversal errors.

The magnitude of CREs for the three flight conditions were aggregated by participant (given they experienced each flight condition twice). Overall, the mean magnitude of the CREs during the disoriented condition was significantly greater than the mean magnitude of CREs for the two oriented conditions (figure 6). A repeated measures ANOVA revealed there was a significant main effect of flight condition for the CRE data, $F(1.007, 35.260) = 126.184$, $p < .001$ (Greenhouse-Geisser corrected). Pairwise comparisons (Bonferroni adjusted) revealed the mean magnitude of the CREs during the *disoriented in formation* condition was significantly greater than CREs during the *oriented* ($p < .001$) and *oriented in formation* ($p < .001$) conditions. These data provide evidence that the participants were disoriented, as intended, during the disoriented condition.
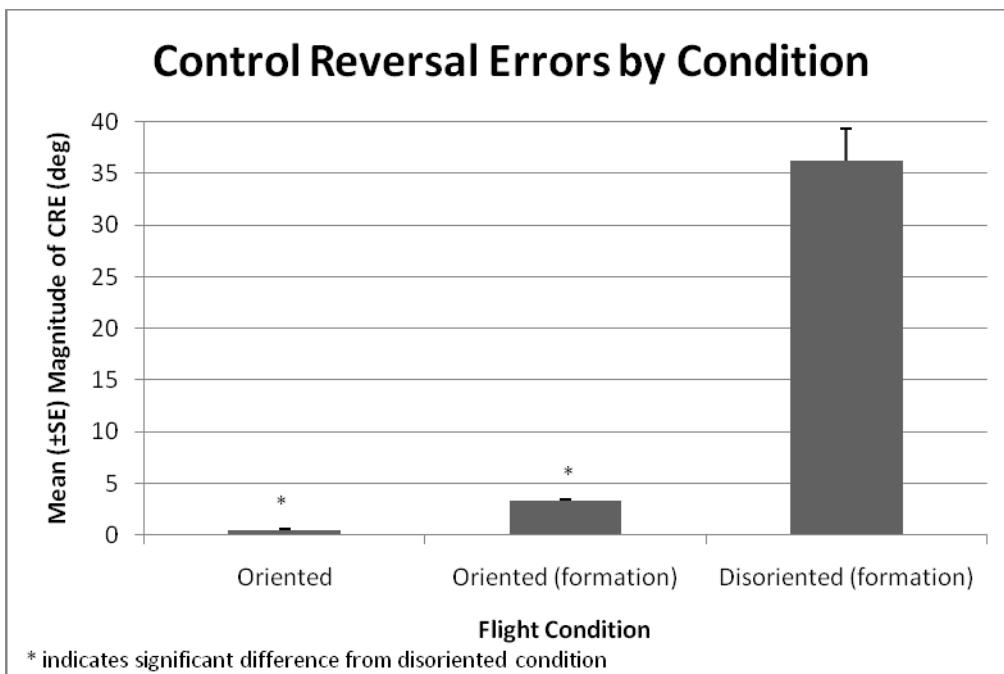
Figure 6. Mean control reversal errors by flight condition.

Cognitive performance

Participants performed one of two cognitive tests during each flight condition, namely a digit span test or an addition task. Participants' responses were recorded and analyzed using Adobe® Audition® 3.0 sound editing software to capture accuracy and response time data. Reaction time was calculated as the time from the end of the test stimulus to the onset of the participants' response, and was scored only for correct responses.

Approximately 4% of the data were missing (19 of 432 data points), due mainly to test administrator error or problems with audio recordings which did not allow for reaction times to be calculated for either test. Those cases with missing data were eliminated from the analysis. Table 2 presents the sample size for each analysis.

Table 2.
Sample sizes for analyses.

Measure	n
Digit span accuracy	33
Digit span reaction time	32
Addition accuracy	34
Addition reaction time	32

Digit span

    Mean digit span accuracy data by flight condition are presented in figure 7. A repeated measures ANOVA revealed a significant main effect of type of flight condition on span length, $F(1.68, 53.747) = 12.591$, $p < .001$ (Greenhouse-Geisser corrected). Pairwise comparisons (Bonferroni adjusted) revealed participants' span length was significantly shorter for the *disoriented* condition than the *oriented* ($p = .001$) and *oriented in formation* ($p = .002$) conditions.
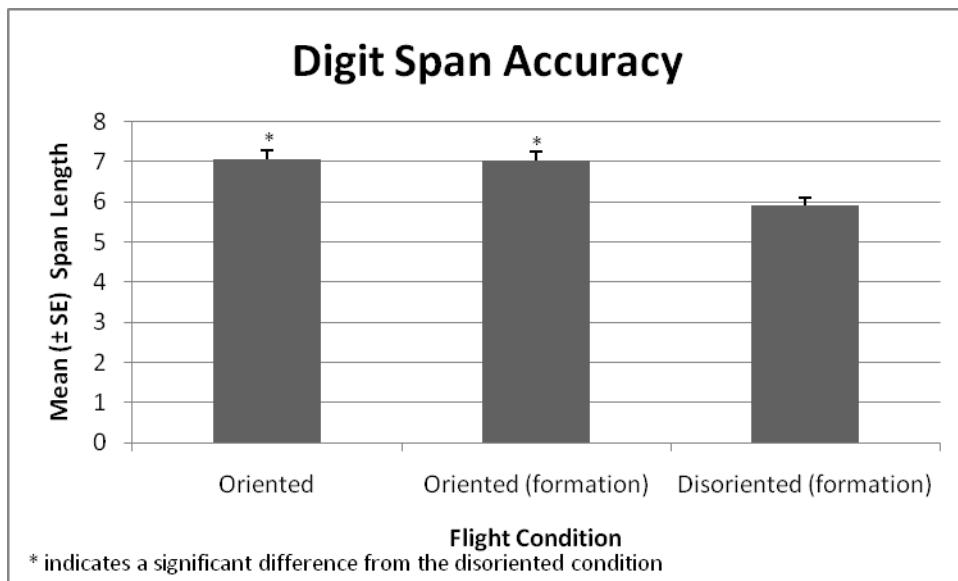
Figure 7. Mean digit span accuracy by flight condition.

    Mean digit span reaction time data by flight condition are presented in figure 8. A repeated measures ANOVA revealed a non-significant effect of flight condition on digit span reaction time, $F (2, 62) = 1.132$, $p = .329$.
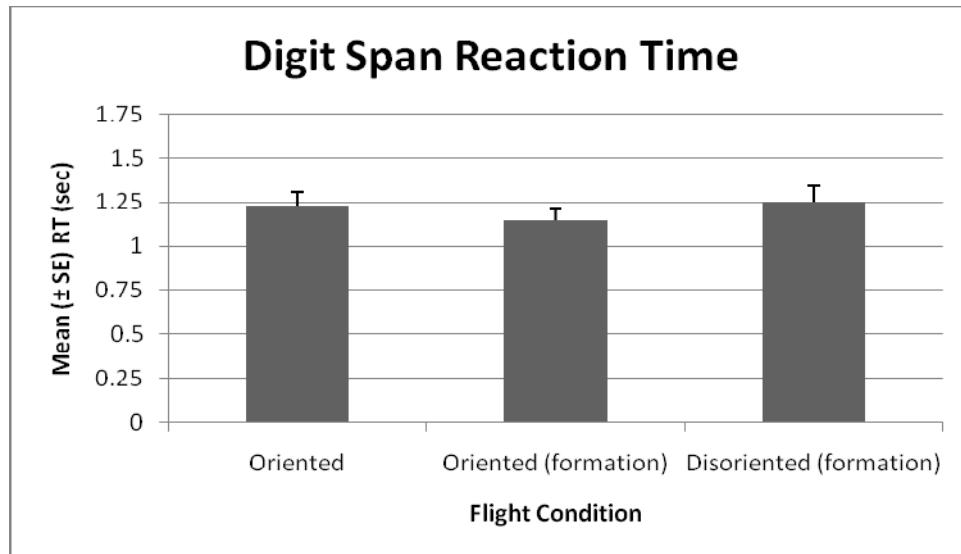
Figure 8. Mean digit span reaction time by flight condition.

Addition task

   Mean addition task accuracy data by flight condition are presented in figure 9. A repeated measures ANOVA revealed a main effect of type of flight condition for accuracy on the addition task, $F(1.368, 45.145) = 34.383$, $p < .001$ (Greenhouse-Geisser corrected). Pairwise comparisons (Bonferroni adjusted) revealed participants' accuracy was significantly worse during the *disoriented* condition than the *oriented* ($p < .001$) and *oriented in formation* conditions ($p < .001$).
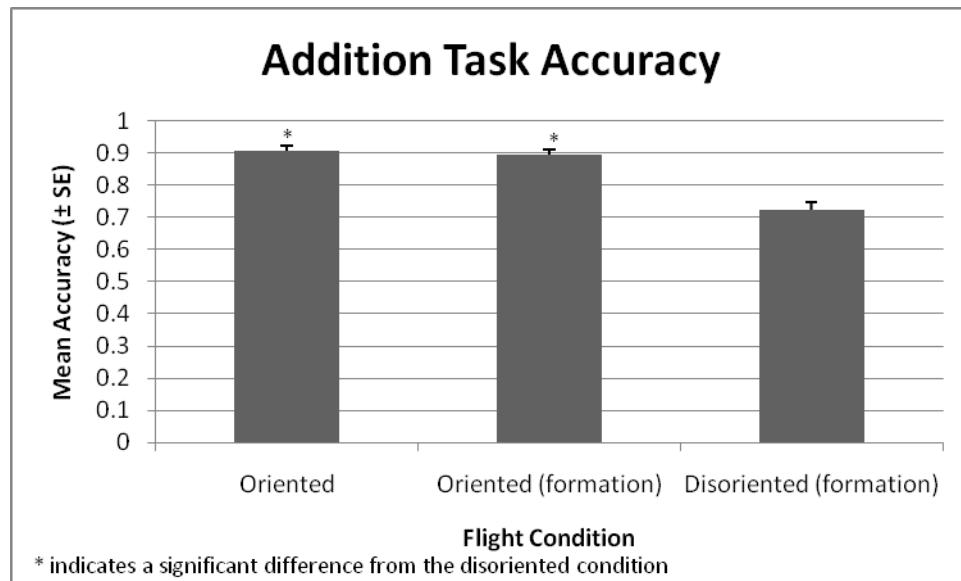

Figure 9. Mean addition task accuracy by flight condition.

Mean addition task reaction time data by flight condition are presented in figure 10. A repeated measures ANOVA revealed a significant main effect of flight condition on participants mean reaction times on the addition task, $F(2, 62) = 19.361$, $p < .001$. Pairwise comparisons (Bonferroni adjusted) revealed participants' mean reaction times during the disoriented condition were significantly slower than the oriented ($p = .001$) and oriented in formation conditions ($p < .001$).
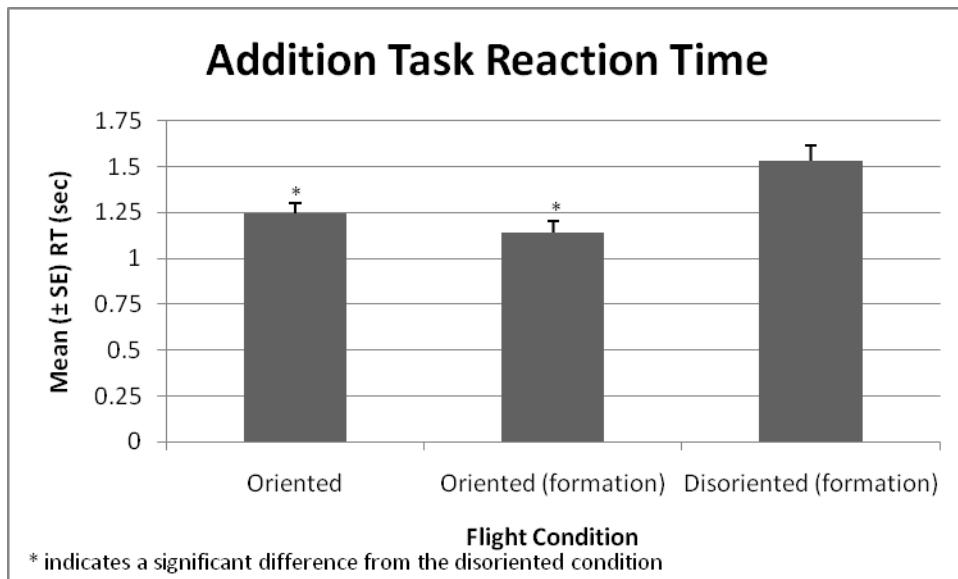
Figure 10. Mean addition task reaction time by flight condition.

Effect of experience on cognitive performance

The sample population of the present study was comprised of relatively inexperienced aviators. Out of the 36 total participants, 26 accumulated 300 or less total flight hours. Given the variability in participants' performance on the cognitive tests, particularly in response times, correlational analyses were conducted to determine the relationship between flight experience and performance. Table 3 presents the results of the correlation analysis. For both cognitive tests, a weak negative correlation emerged between participants' reaction times and flight hours. In general, more experienced pilots took less time to respond. There was no relationship between participants' flight hours and their accuracy on the cognitive tests.

Table 3.
Results of correlation analysis between total flight hours and cognitive performance.

Cognitive test	Flight condition	Pearson's correlation (r)	Significance (p)
Digit span- accuracy	Oriented	.041	.816
	Oriented in formation	-.148	.395
	Disoriented in formation	.251	.139
Digit span- reaction time	Oriented	-.361	.039
	Oriented in formation	-.415	.015
	Disoriented in formation	-.380	.024
Addition task- accuracy	Oriented	.057	.746
	Oriented in formation	.226	.199
	Disoriented in formation	.000	.999
Addition task- reaction time	Oriented	-.363	.035
	Oriented in formation	-.247	.166
	Disoriented in formation	-.226	.199

Simulator Sickness Questionnaire data

According to the scoring criteria of Stanney, Kennedy, and Drexler (1997), the entire flight profile produced negligible symptoms of simulator sickness as the mean total SSQ score was less than 5 (figure 11). However, there were six participants who reported total SSQ scores greater than 10. To test the hypothesis that higher SSQ scores were associated with poorer performance on the cognitive tests, a correlational analysis (Pearson's *r*) was performed (table 4). For the accuracy data, there were no significant negative correlations between total SSQ score and performance for both cognitive tests. For the reaction time data, there were no significant positive correlations between total SSQ scores and reaction time for both cognitive tests.
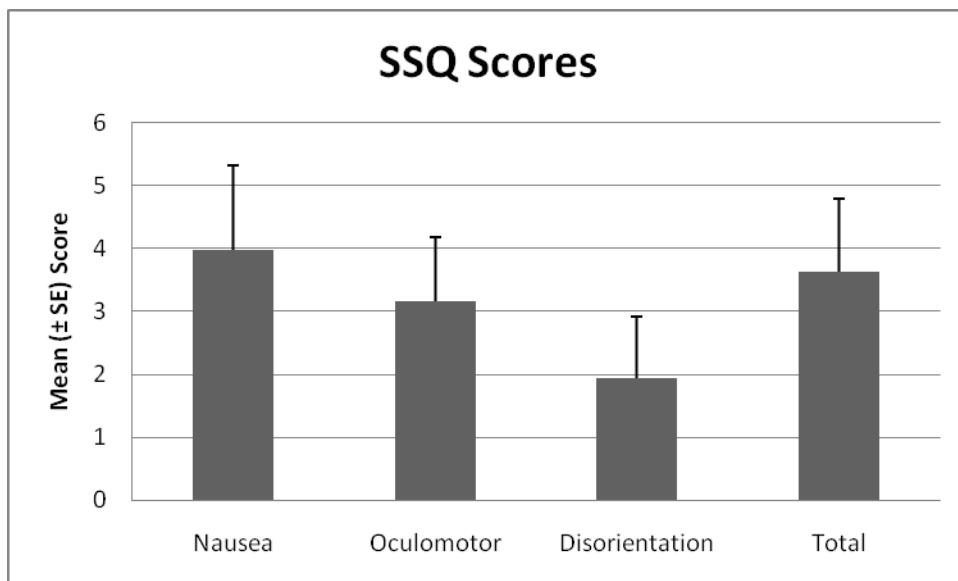
Figure 11. Mean subcale and total SSQ scores.

Table 4.
Results of correlation analysis between total SSQ score and cognitive performance.

Cognitive test	Flight condition	Pearson's correlation (*r*)	Significance (*p*)
Digit span- accuracy	Oriented	0.425	.012
	Oriented in formation	0.447	.007
	Disoriented in formation	-0.016	.928
Digit span- reaction time	Oriented	0.122	.500
	Oriented in formation	0.099	.579
	Disoriented in formation	0.169	.333
Addition task- accuracy	Oriented	0.314	.066
	Oriented in formation	0.161	.364
	Disoriented in formation	0.152	.378
Addition task- reaction time	Oriented	-0.196	.268
	Oriented in formation	-0.227	.204
	Disoriented in formation	-0.052	.770

Discussion

The results of the present study suggest that spatial disorientation negatively impacts cognitive processing. Specifically, the disoriented condition impaired participants' accuracy on both cognitive tests. Participants' reaction times were also negatively impacted by SD during the addition test. These results are in accordance with the "posture first principle," as that there is a natural tendency to direct all mental resources to regaining orientation and stability when balance and orientation are unstable. The present study demonstrated that cognitive functions other than spatial processing can be negatively affected by SD in an aviation setting.

During flight training, pilots are instructed that in times of crisis, task priorities should be to aviate, navigate, and then communicate. The results of the present study support this training, as the ability to multitask while disoriented is negatively affected. The core of SD prevention is aircrew training in the recognition and awareness of SD (Baijal, Jha, Sinha, & Sharma, 2006). The cognitive effects of SD should also be taught, in terms of the information processing model (Hendy, East, & Farrell, 2001). Cognitive impairments, including errors and slowed responses, may manifest as a result of the demand of resources to establish orientation.

In addition, the results have implications for future cockpit display design. For example, the field of *adaptive automation* uses real-time neurophysiological sensing technologies that can determine a human's cognitive state while interacting with computer-based technologies. With regard to aviation, information about a pilot's cognitive state would help tailor the cockpit display content as well as the amount of automation (DeAngelis, 2008). Information about cognitive decrements due to SD would greatly contribute to these advanced displays.

Recently, Gresty and Golding (2009) discussed the implications of cognitive impairment during SD. They discussed how stress and anxiety of actual flight may interact with the disorientation in a "highly negative manner." The present study was the first step in creating a more representative environment that included increased workload and stress due to participants controlling the flight simulator. Gresty and Golding also discussed that familiarity and practice with a test gives protection against disorientation. The present study provided conflicting evidence, as participants were given practice on the both cognitive tests and still were negatively affected during the disorienting conditions.

Although it was not an original objective, flight experience was examined to determine its influence on the relationship between SD and cognitive functioning. For both cognitive tests, there were weak negative correlations between participants' reaction times and flight hours. It should be noted that these weak correlations were found for all flight conditions, not only the disoriented condition. Given the literature regarding the effect of experience on SD susceptibility, one could speculate that flight experience may influence the way SD affects cognitive functioning. According to Gawron (2004), factors such as number of total flight hours and training are related to SD susceptibility. It has been reported that less experienced pilots have the greatest risk of SD, but Gawron adds that flight hours in a specific type of aircraft may be a better predictor of SD vulnerability. In addition, there are certain learned behaviors that have been shown to counter SD by redirecting attention from false orientation sensations, including quick head shakes and readjusting seat harnesses (Gawron). Disorientation may still degrade cognitive functioning in an experienced aviator, but perhaps to a lesser extent compared to its effect on a less experienced pilot. Of course this is speculation, and future studies with more experienced pilots are needed.

It was unexpected that cognitive performance in the two oriented conditions was not significantly different from each other, given the increased workload of the *oriented in formation* condition. Perhaps the *oriented* condition was not stimulating enough and the pilots' boredom degraded their performance. Previous research has shown low arousal can result in less than optimal performance (Cohen, 1980). On the other hand, perhaps the workload generated under the *oriented in formation* condition was not as high as assumed. It would have been useful to measure the pilot participants' perception of workload after each maneuver to allow for relevant comparisons.

Limitations

One limitation of the current study was the lack of vestibular stimulation during the disoriented condition. In this effort, disorientation was achieved through the restriction of visual information (flight instruments and outside references). Due to the extreme unusual attitudes possible during the disoriented flight condition (tumbling loops, rolls, and inverted flight), the USAARL simulator could not be allowed to move freely (be on "motion"). Such freedom would have exceeded hardware and software limitations which would have resulted in a software crash or "freezing" of the simulator (stopping the simulator's motion and visuals). Therefore, it was necessary to override this crash feature, restricting the actual pitch, roll, and yaw accelerations while still allowing the outside visuals and flight instruments to move as if the aircraft was in motion. It is likely that a simulator capable of producing such extreme disorienting accelerations

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(e.g., the TNO [2010] Desdemona) would have made the current profile more representative of Type III (incapacitating) disorientation, instead of Type II (recognized). The authors acknowledge, however, the differences between vestibular stimuli produced in a simulator and actual flight.

In addition, the inability of the present study to find evidence of SD negatively impacting reaction time on the digit span tests could be due to the variability in the participants' responses to the task. Participants varied in the way they repeated the string on numbers, with some taking longer to respond but completed the string without further delay, while some began with the first few digits right away but paused in the middle of their response. This inconsistency most likely contributed to the non-significant results. Traditionally, the digit span test is only scored for accuracy and not reaction time.

Conclusion

The present study examined the effect of recognized SD on cognitive processing and provided support that SD can negatively impact cognitive performance. Knowledge of cognitive processing during disorientation can contribute to SD mitigation strategies, including training techniques and future cockpit display design. Future research should employ a flight simulator with the capability to provide vestibular stimulation through the range of unusual attitudes to investigate the influence of the vestibular accelerations. In addition, the role of flight experience should be examined in future studies investigating the impact of SD on cognitive processing.

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Profile scripts.

1. Oriented Condition

<u>IC</u>: IC 1. Visibility 11 miles.

<u>Researcher will read to Subject</u>:

You are on a VFR flight in support of a research mission. After receiving clearance from the tower for takeoff, you will climb straight ahead to 7500 feet on heading 180. Upon reaching 7500 feet, you will be asked to perform one of the two memory tasks. Do you have any questions?

<u>Research Pilot actions</u>:

On the ground: "Army Copter 23748. Altimeter 2992. Winds calm, cleared for takeoff."

<u>Researcher action</u>: At 7500, begin memory task.

2. Oriented in formation Condition

IC: IC 1. Visibility: 0.5 miles. Leadship 2: playback.

<u>Researcher will read to Subject</u>:

You are on a multiship IFR flight in support of a research mission. The winds are calm with ½ mile visibility. There are no ceilings. As Chalk 2, you have been tasked with external communication and transponder responsibilities. After receiving clearance from the tower for takeoff, you will climb straight ahead to 8000 feet on heading of 180. Your job on this flight is to fly and communicate to the tower and air traffic controllers. Your RL2 copilot is fresh out of flight school and cannot be trusted to fly the aircraft under such conditions, however, is available to move any switches and select frequencies as you direct. He will also remind you of any communication requirement that you fail to complete. Upon reaching 8000 feet, you will be asked to perform one of the two memory tasks. Do you have any questions?

<u>Research Pilot actions</u>:

On the ground: "Army Copter 23748. Squawk 4321. Altimeter 2992. After takeoff, climb straight ahead on heading 180 to 8000 feet. Contact Cairns Approach on 136.1 passing through 800 feet. Winds calm, cleared for takeoff."

After initial contact (passing through 800 feet): "Army Copter 23748. I have no radar contact. Recycle transponder, squawk 4321." (After subject response) "Army Copter 23748. Still no

contact. I believe your transponder is inop. Report passing through every 1000 feet and report any heading changes greater than 10 degrees."

Subject must report passing through 2000 feet.

Passing through 2500 feet: "Army Copter 23748. Squawk 4573. Let's see if that works." (After response) "That didn't work. Continue altitude reports."

Subject must report passing through 3000 feet.

Passing through 3500 feet: "Army Copter 23748. Contact Cairns Approach on 134.75."

Subject must report passing through 4000 feet.

Passing through 4500 feet: "Army Copter 23748. New altimeter setting 2993.

Subject must report passing through 5000 feet.

Passing through 5500 feet: "Army Copter 23748. You have traffic at one mile at your two o'clock passing from left to right at 6000 feet. Do you have contact?" (After response) Army Copter 23748. Traffic no factor."

Subject must report passing through 6000 feet.

Passing through 6500 feet: "Army Copter 23748. Are you on that research mission we were briefed about?" (After response) "Roger that. Just curious. How long will you be at 8000 feet?" (After response) "Roger."

Subject must report passing through 7000 feet.

Passing through 7500 feet: "Army Copter 23748. New altimeter 2992. Advised when established at 8000 feet."

Subject must report passing through 8000 feet.

Researcher action: At 8000 feet, begin memory task.

3. Disoriented in formation Condition

IC: IC 19. Visibility: 0.5 miles. **Crash Override**. Leadship 1: Playback. Cover flight instruments.

Research Pilot: Ensure the simulator is in **Crash Override**.

Researcher will read to Subject:

You are on a multiship IFR flight in support of a research mission. Because this is a research mission, your flight instruments have been covered. You are established at 15000 feet flying at 80 knots. The winds are calm with ½ mile visibility. There are no ceilings. There are no external communication requirements. Your job on this flight is to follow the Leadship wherever he leads you. If at any point you lose the Leadship, do your best not to crash the simulator into the ground. During this phase, you will be asked to perform one of the two memory tasks. If you successfully complete the entire memory task, you will be allowed access to your flight instruments once again. Do you have any questions?

Research Pilot actions:

Within one minute of flight commencement: "Army Copter 23748, continue climb to 18000 feet."

Three minutes into flight: "Army Copter 23748. Say type aircraft."   (After subject response) "Confirm you are a flight of two."

Five minutes into the flight: "Army Copter 23748. Say amount of fuel onboard." (After subject response) "Roger. I may need you to slow down for converging traffic."

Six minutes into flight: "Army Copter 23748. Traffic is no factor. Contact Cairns Approach on 133.45."

Seven minutes into flight: "Army Copter 23748. Confirm that Cairns Army Airfield is your final destination." (After subject response) "Roger."

Researcher action: Begin memory task when Leadship disappears or is lost by the subject.

Simulator Sickness Questionnaire.

Participant # _____

For each symptom, please circle the rating that applies to you **RIGHT NOW**.

SYMPTOM		**RATING**		
General discomfort	none	slight	moderate	severe
Fatigue	none	slight	moderate	severe
Headache	none	slight	moderate	severe
Eye strain	none	slight	moderate	severe
Difficulty focusing	none	slight	moderate	severe
Salivation increased	none	slight	moderate	severe
Sweating	none	slight	moderate	severe
Nausea	none	slight	moderate	severe
Difficulty concentrating	none	slight	moderate	severe
"Fullness of the head"	none	slight	moderate	severe
Blurred vision	none	slight	moderate	severe
Dizziness with eyes open	none	slight	moderate	severe
Dizziness with eyes closed	none	slight	moderate	severe
Vertigo	none	slight	moderate	severe
Stomach awareness	none	slight	moderate	severe
Burping	none	slight	moderate	severe

Other (please describe)

_____

_____

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